جامعة القاهرة

Active Circuits
Lecture 9: Active Inductors, Negative Resistance and LC-Ladder Filters

ELC 302 – Spring 2013

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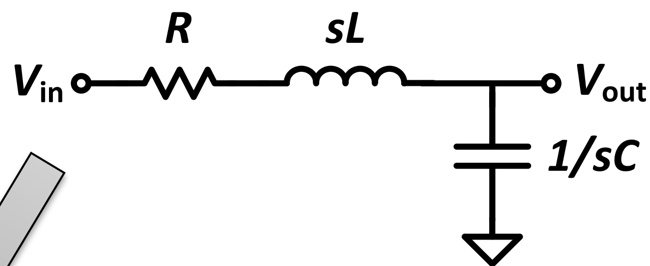
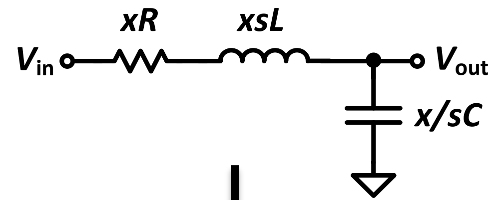
Other Alternatives

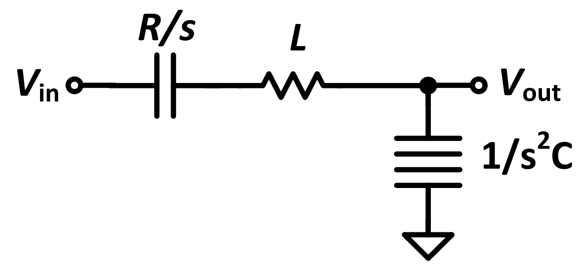
$$H(s)=\frac{\frac{1}{LC}}{s^2+s\left(\frac{R}{L}\right)+\frac{1}{LC}}$$

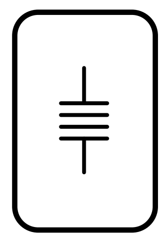




$x = 1/s$

Bruton's transformation





$\frac{1}{s^2C} = -\frac{1}{\omega^2 C} \equiv$ FDNR

Frequency-Dependent Negative Resistance

Replace this RLC filter with an Active Opamp RC filters

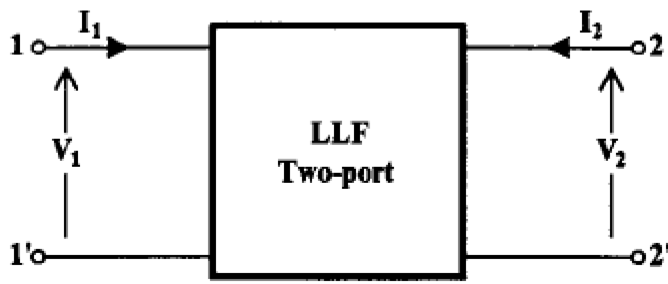
Use Active Circuits to Emulate "L" ≡ Replace L with a circuit

Leapfrog Filters

Emulation of RLC Filters using Opamps

- Active Inductors – Inductor Emulations.
- FDNR: Frequency Dependent Negative Resistance
- (LC Ladder Filters) Leapfrog Filter Architectures.

Inductor Emulation Using Two-port Network



$$Z_{i1} \equiv \frac{V_1}{I_1} = \frac{a_{11}Z_L + a_{12}}{a_{21}Z_L + a_{22}}$$

$$V_1 = a_{11}V_2 + a_{12}(-I_2)$$

$$I_1 = a_{21}V_2 + a_{22}(-I_2)$$

GIC (General Impedance Converter)

$a_{11}, a_{22} \neq 0$ while $a_{12} = a_{21} = 0$

$$Z_{i1} = \frac{V_1}{I_1} = G_a Z_L(s) \quad \text{while } G_a = \frac{a_{11}}{a_{22}} = f(s)$$

$$[T] = [A] = \begin{bmatrix} k & 0 \\ 0 & \dfrac{k}{f(s)} \end{bmatrix}$$

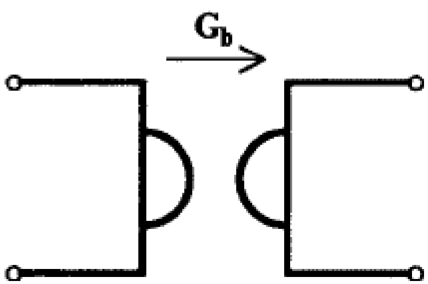
GII (General Impedance Inverter)

$a_{11} = a_{22} = 0$ while $a_{12}, a_{21} \neq 0$

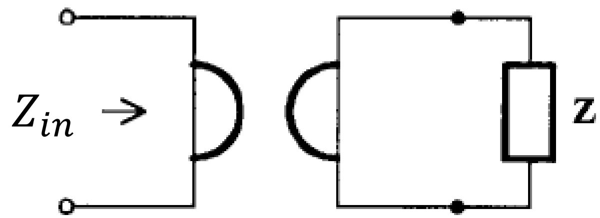
$$Z_{i1} = \frac{a_{12}}{a_{21}} \frac{1}{Z_L} = G_b \frac{1}{Z_L} \qquad G_b = \frac{a_{12}}{a_{21}}$$

$$[A] = \begin{bmatrix} 0 & a_{12} \\ a_{21} & 0 \end{bmatrix}$$

Gyrator – Positive Impedance Inverter



$$\begin{bmatrix} 0 & \pm\frac{1}{g_2} \\ \pm g_1 & 0 \end{bmatrix}$$

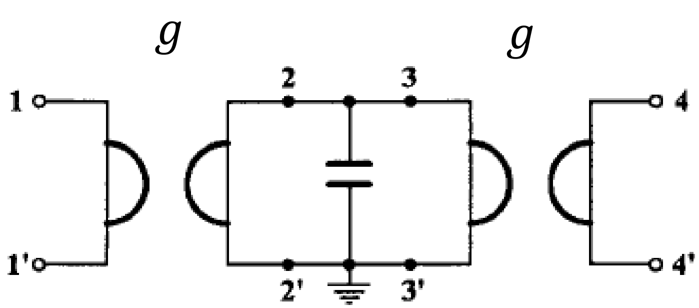


$$Z_{in} = \frac{1}{g_1 g_2} \cdot \frac{1}{Z}$$

If $Z = \frac{1}{sC} \Rightarrow Z_{in} = s\frac{C}{g_1 g_2} = sL_{eq}$ ⟹ $L_{eq} = \frac{C}{g_1 g_2}$

Good For Grounded Inductors

Floating inductor



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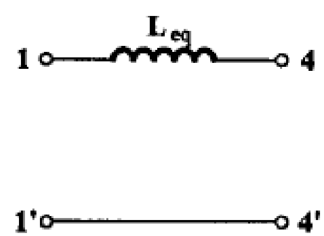
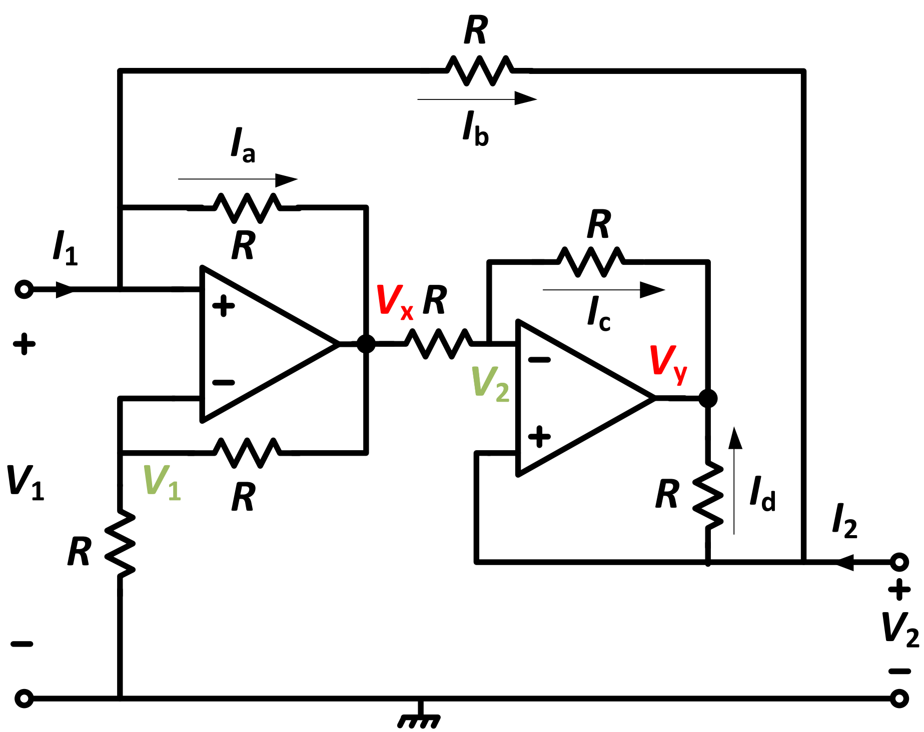


$$L_{eq} = \frac{C}{g_1 g_2}$$

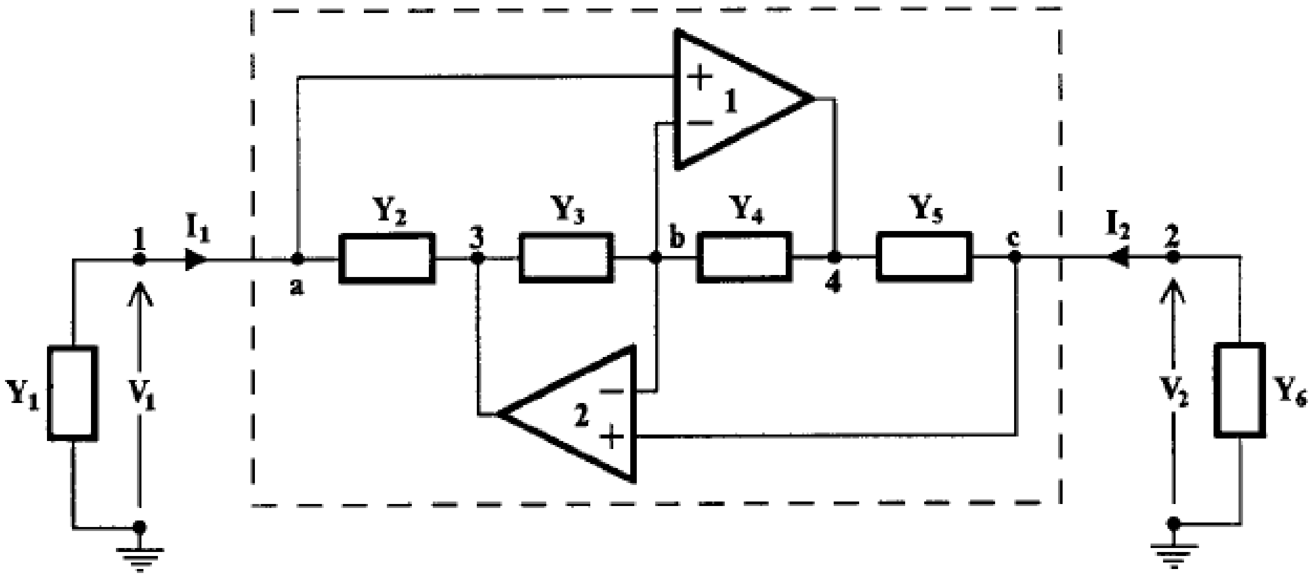
Gyrator Example



- $V_x = 2V_1$
- $I_a = (V_1 - V_x)/R$
- $I_b = \frac{(V_1 - V_2)}{R}$
- $I_c = \frac{V_x - V_2}{R}$
- $I_1 = I_a + I_b$
- $V_y = V_2 - RI_c$
- $I_d = \frac{(V_2 - V_y)}{R}$
- $I_2 = I_d - I_b$
- $[A] = \begin{bmatrix} 0 & -R \\ -\frac{1}{R} & 0 \end{bmatrix}$

Gyrator Resistance = R

Antoniou GIC



$$[A] = \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{Y_2 Y_4}{Y_3 Y_5} \end{bmatrix}$$

$$f(s) = \frac{Y_3 Y_5}{Y_2 Y_4}$$

$$V_1 = V_b = V_2$$

$$I_1 = Y_2 (V_1 - V_3)$$

$$Y_3 (V_3 - V_1) = Y_4 (V_1 - V_4)$$

$$Y_5 (V_4 - V_1) = -I_2$$

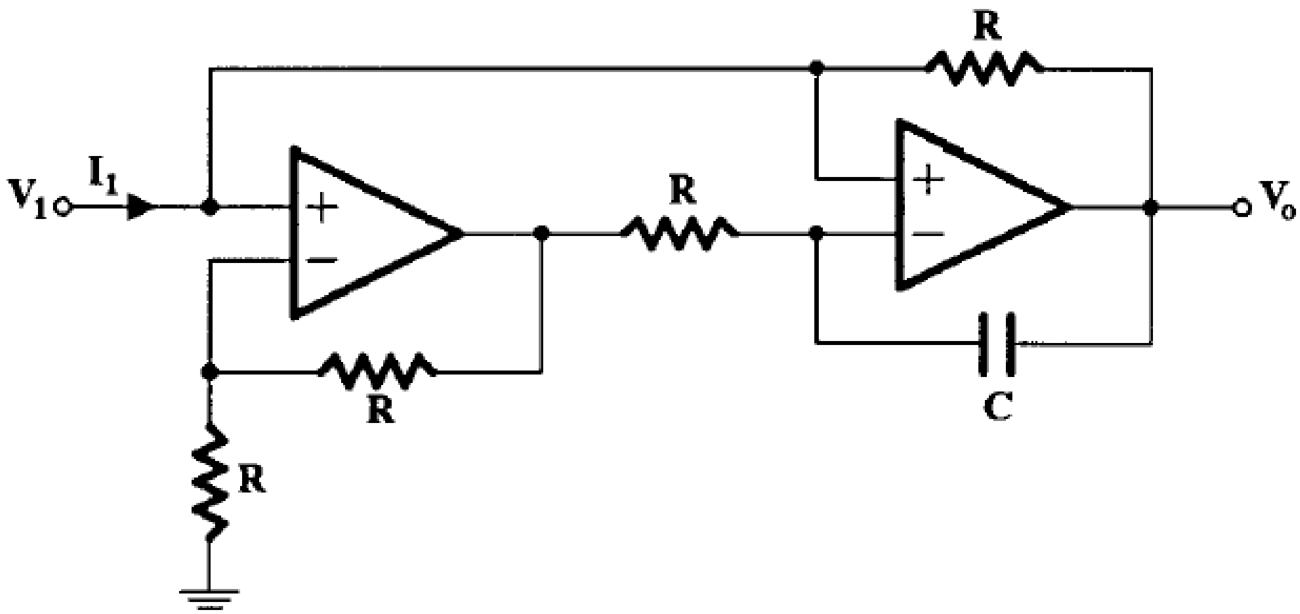
$$I_1 = \frac{Y_2 Y_4}{Y_3 Y_5}(-I_2)$$

Assuming that $Y_2 = Y_3 = Y_4 = Y_6 = R^{-1}$ and $Y_5 = sC$

$$Z_{i,1} \equiv \frac{V_1}{I_1} = f(s) \cdot \frac{1}{Y_6} = sCR^2 \rightarrow L_{eq} = CR^2$$

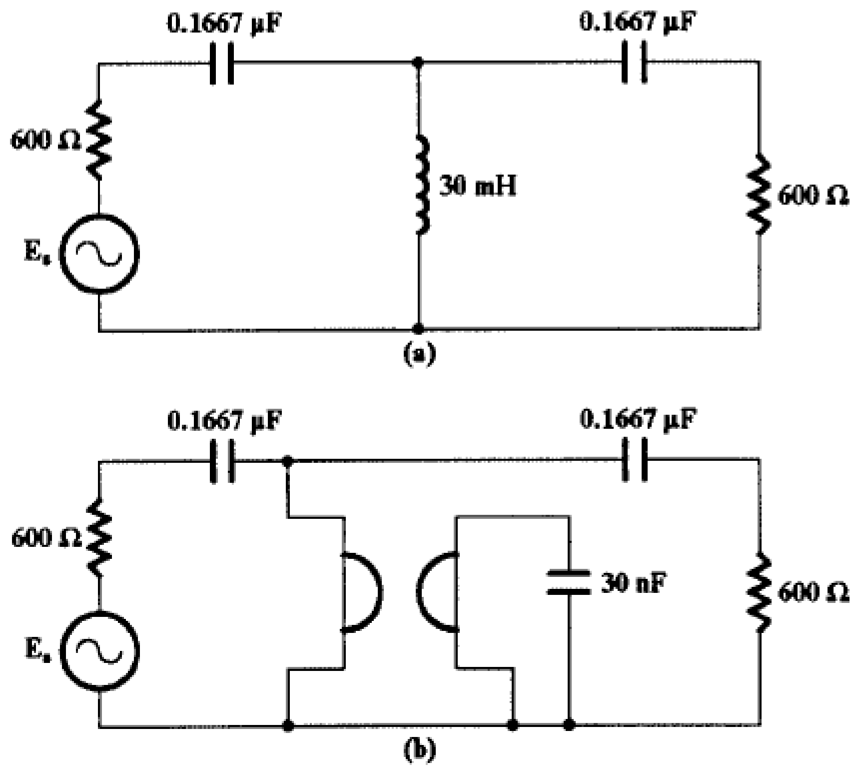
$$Z_{i,2} \equiv \frac{V_2}{I_2} = \frac{1}{f(s)} \frac{1}{Y_1}$$

Riordan Gyrator



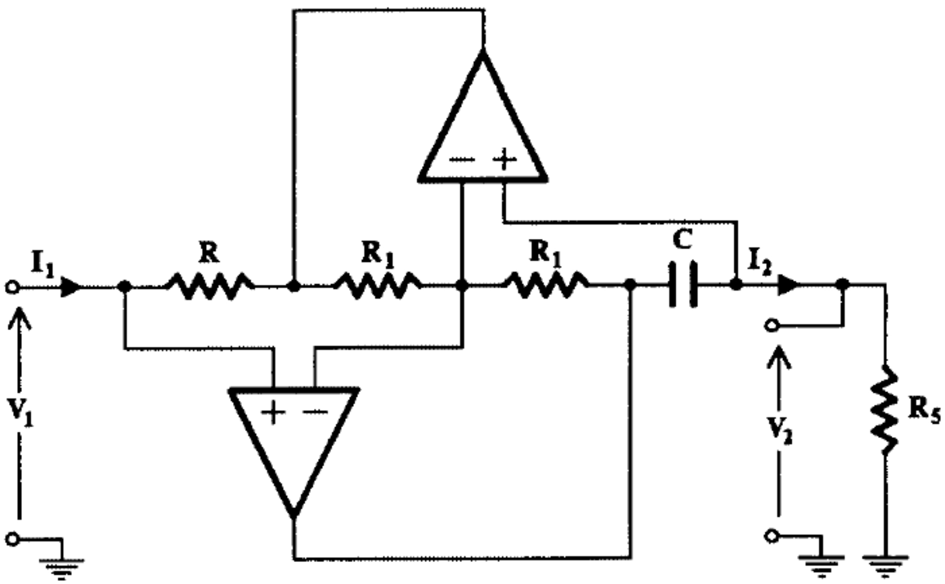
- $Z_{in} = \frac{V_1}{I_1} = sCR^2$
- $L_{eq} = CR^2$

Filter Example

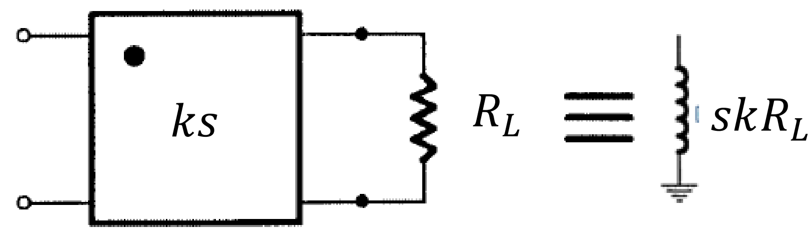


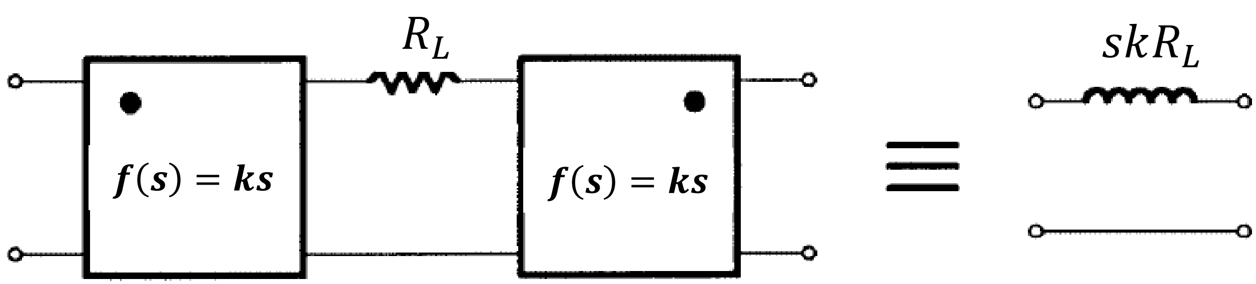
For Gyration resistance $=1k\Omega$

Antoniou GIC



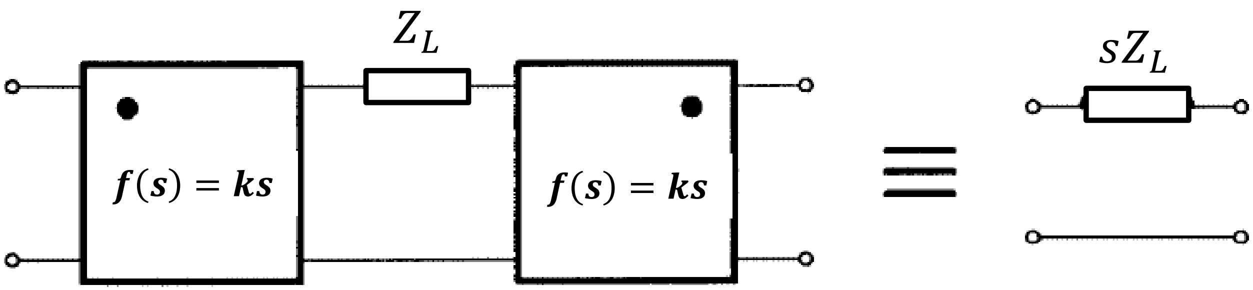
$$f(s) = sCR = ks$$



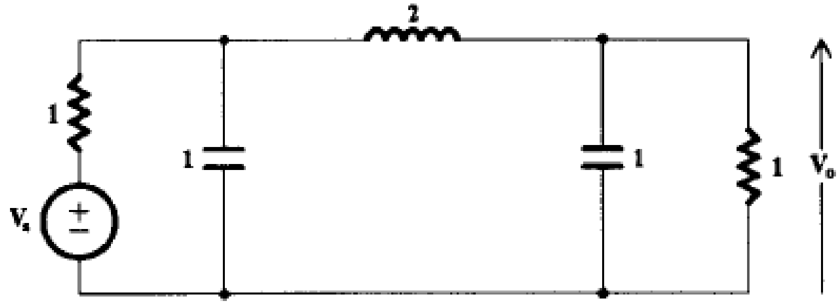


- Note: Inductance emulation is optimum in case of no floating inductors i.e., LC high-pass filters

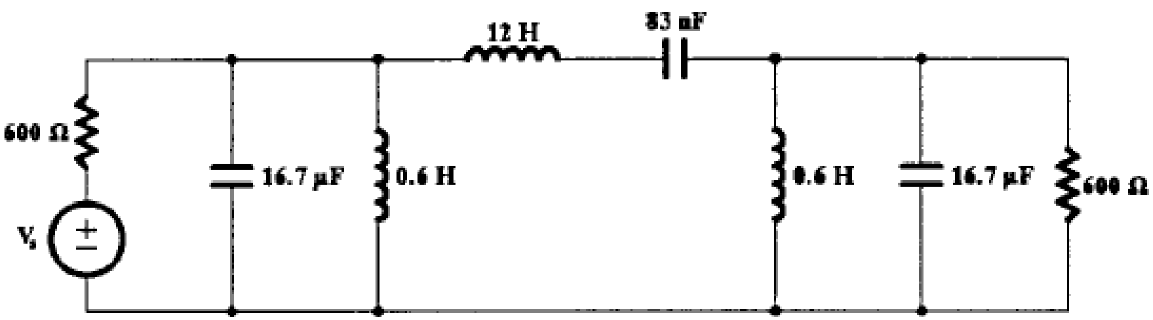
Antoniou GIC



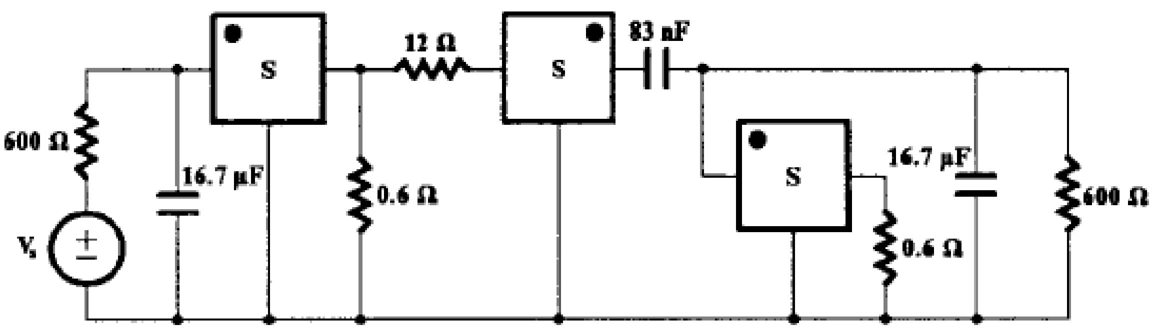
Example



(a)



(b)



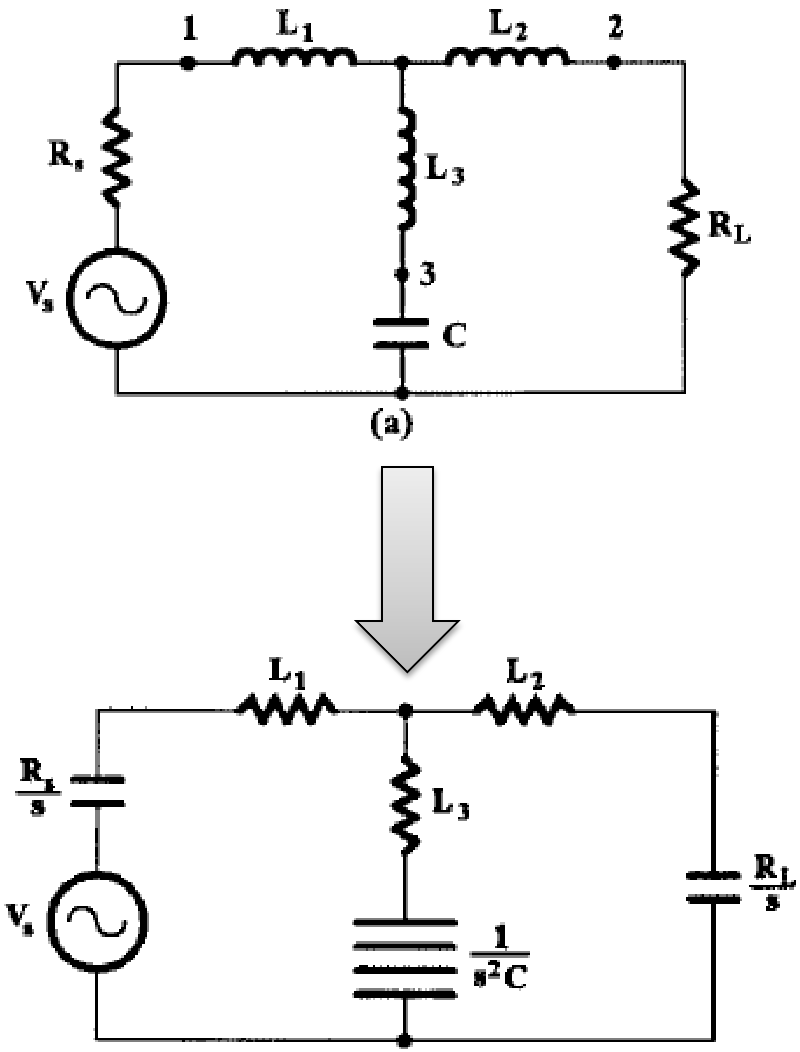
(c)

3rd Order LPF

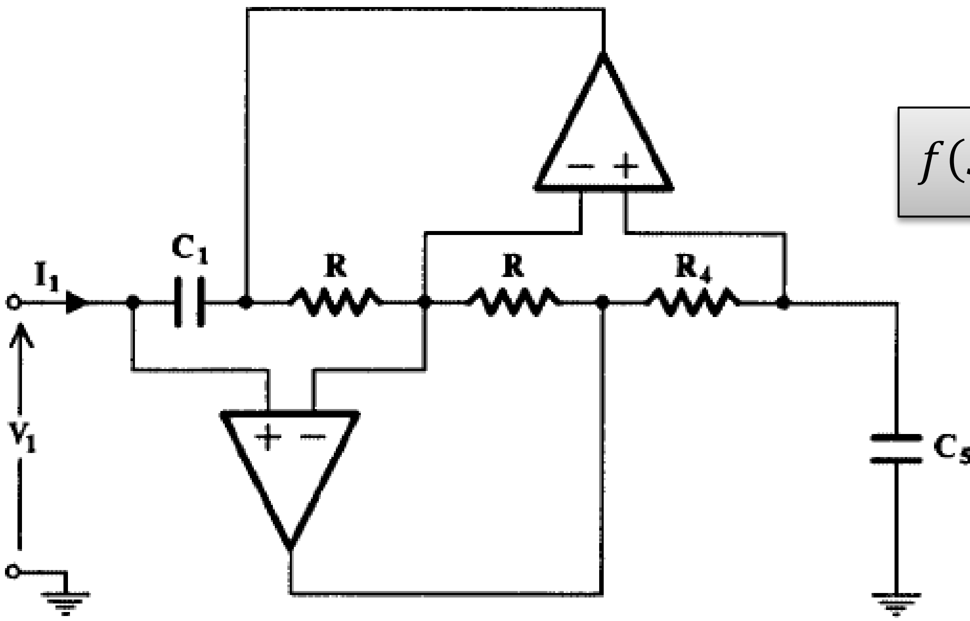
6th Order BPF

$$\omega_o = 1 \text{ krad}/s,\ B = 100 \text{ rad}/\text{s}$$

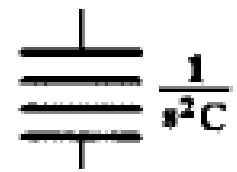
Bruton’s transformation



FDNR : Frequency-Dependent Negative Resistance



$$f(s) = \frac{1}{sC_1R_4} \Rightarrow Z_{in} = \frac{1}{s^2C_1C_5R_4}$$



$$C = C_1C_5R_4$$

- Bruton's inductor simulation based on FDNR
- Most suitable for LC LPF with minimum cap realization